# Manufacturing Demonstration Facility

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arpa·e
CHANGING WHAT'S POSSIBLE

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ORNL is managed by UT-Battelle
for the US Department of Energy

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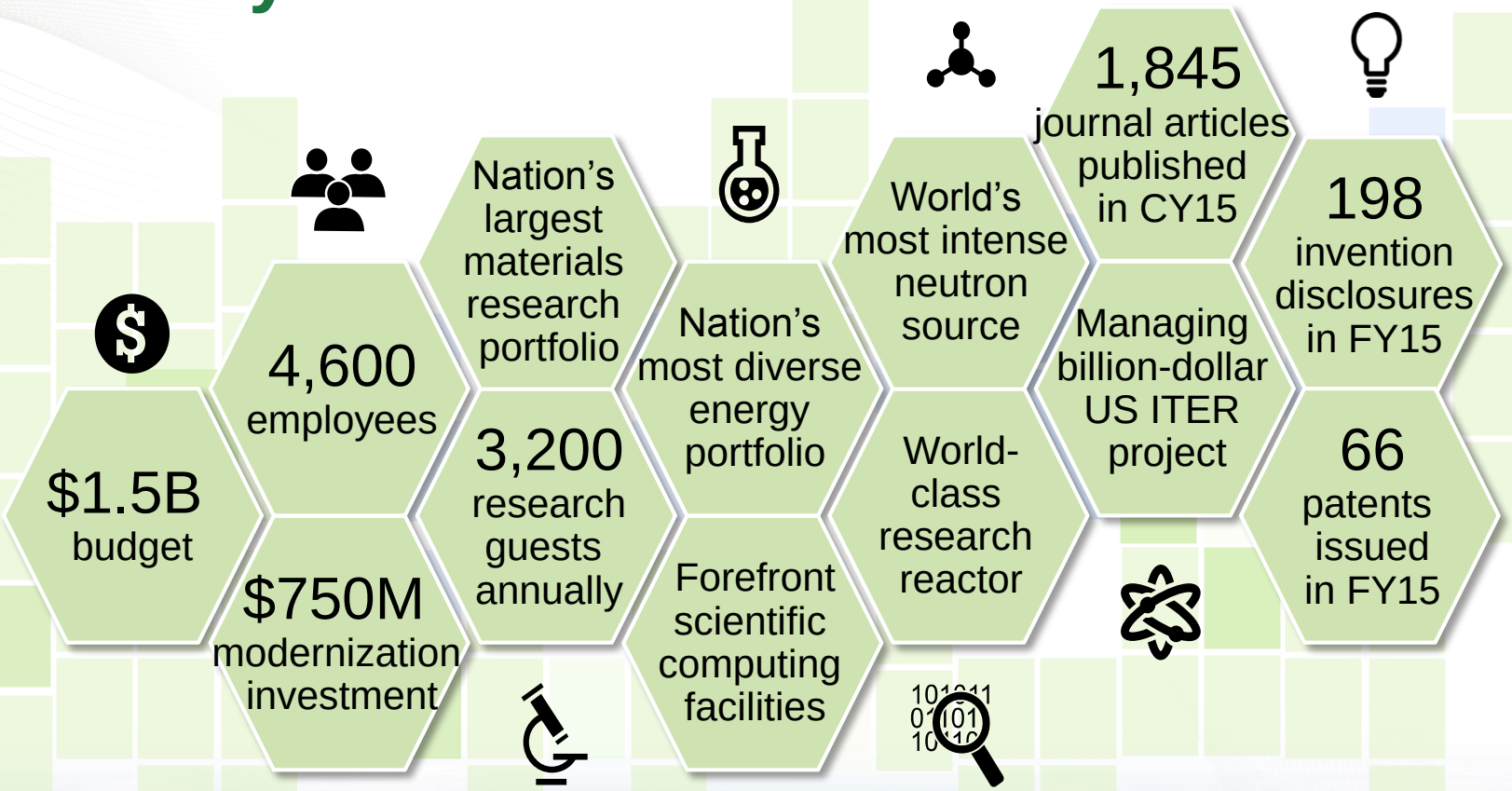
# Today, ORNL is a leading science and energy laboratory




# The Manufacturing Demonstration Facility
## at Oak Ridge National Laboratory

### Core Research and Development

- R&D in materials, systems, and computational applications to develop broad of additive manufacturing

### Industry Collaborations

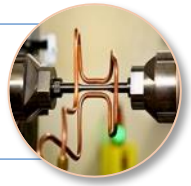
- Cooperative research to develop and demonstrate advanced manufacturing to industry in energy related fields

### Education and Training

- Internships, academic collaborations, workshops, training programs, and course curriculum for universities and community colleges.

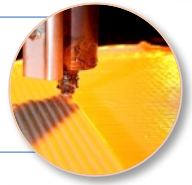
**Neutron scattering: SNS and HFIR**

- World's most intense pulsed neutron beams
- World's highest flux reactor-based neutron source



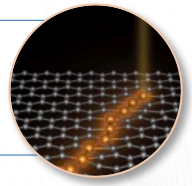
**Advanced Materials**

- DOE lead lab for basic to applied materials R&D
- Technology transfer: Billion dollar impacts



**Leadership-class computing: Titan**

- Nation's most powerful open science supercomputer



**Advanced Manufacturing**

- Novel materials
- Advanced processing

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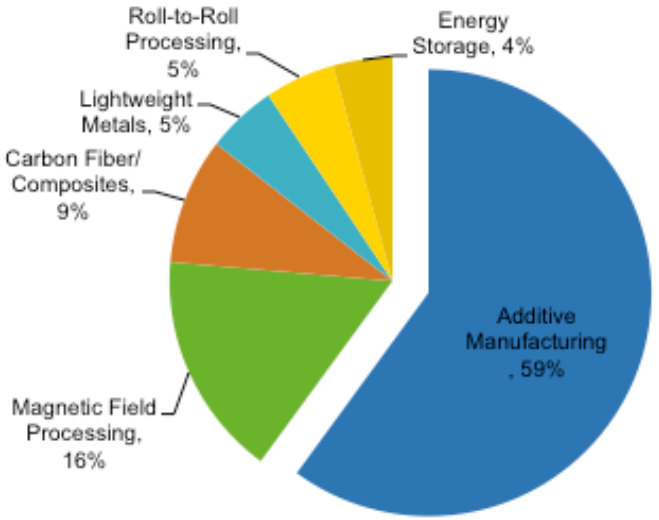
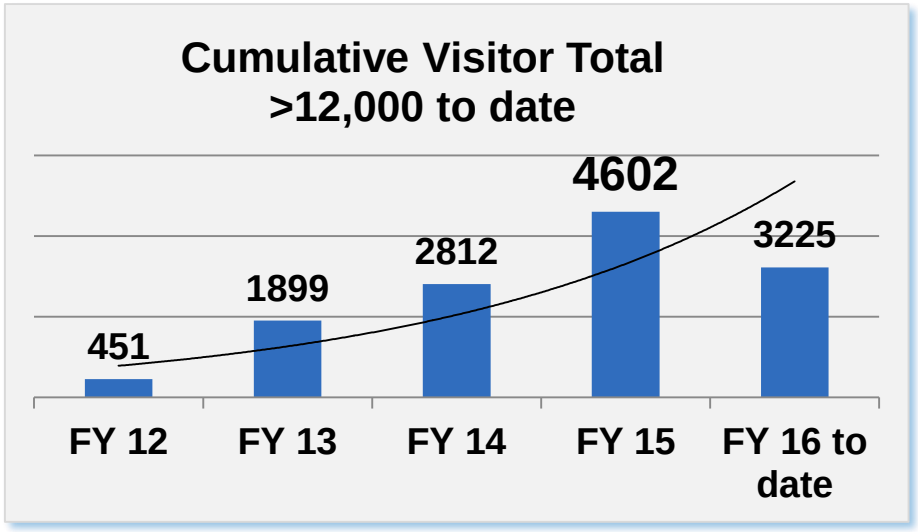
# MDF Quick Stats

102 projects and counting

***Company Size***

- **56 small, medium**
- **34 large**




*Quick Facts*

- **>100 active or completed projects across 24+ industry sectors**
- **Approaching 50 completed projects with 10 going into phase 2**
- **Over 100 publications this year**
- **More than 12,000 visitors**

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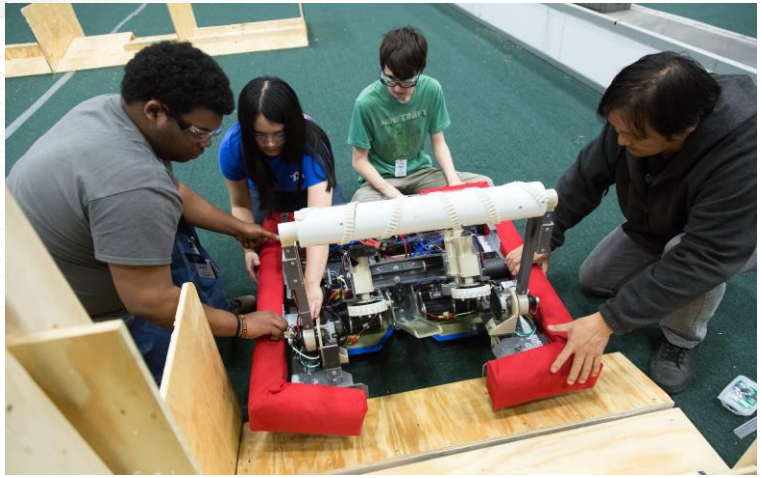
# STEM
## Science, Technology, Engineering & Mathematics

**FY15-16 Activities**



### 2016 FIRST Robotics

- >750 students engaged, 26 teams FRC
- Over 5 Years of Mentorship
- 3 High Schools Use MDF on Nightly Basis, 50 to 200 Students FRC
- Most Recent Trends in Manufacturing

**DOE-AMO enabled**

- **400 desktop printers 2014 FIRST Robotics** Partnering with **America Makes**
- Initiated the Robotics Internship Program this year

- **109 students Summer 2016**
  - 80 Students Summer of 2015
  - 50 Students Summer of 2014
  - Teams of 5 Take on Projects
  - High School to Graduate Students
  - Projects Include Prosthetics, Robotic Design, Software for AM, Efficient Propeller Design, etc.

FLL FIRST LEGO League

FRC FIRST Robotics Competition

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# Additive Manufacturing's Role in Enhancing the Clean Energy Economy

- ✓ Innovation
- ✓ Part Consolidation
- ✓ Lower Energy Consumption
- ✓ Less Waste
- ✓ Reduced Time to Market
- ✓ Light-weighting
- ✓ Agility of Operations

**Reduced Time to Market**

Cummins low-cost, hybrid mold for injection molding demonstrated the ability to lower costs for manufacturing injection molds by **60%.**

*DOE-AMO, R. Dehoff*

**Light-weighting**

3D Printed Shelby Cobra printed on the BAAM illustrates the most **energy efficient** way to produce a car.

*DOE-AMO, L. Love*

**Agility of Manufacturing Operations**

BAAM 3D printed mold for composite hood was fabricated in **<2 days** and used **<$2,500** in materials.

*DOE-AMO, L. Love*

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# Additive Manufacturing's Role in Enhancing the Clean Energy Economy Cont.

**Innovation**

ORNL's 80 kW Inverter module (Left) has **~3.1x** the power density of a Nissan LEAF (Right)

*Vehicle Technologies, B. Ozpineci*

**Part Consolidation**

Underwater Robotic Arm with **7 degrees of freedom** is **neutrally buoyant**. By utilizing AM fabrication number of individual components was reduced from **250 to 49**, and weight of each arm from **80 lbs. to 20 lbs.**

*ONR, L. Love*

**Lower Energy Consumption**

(BAAM-CI) operates at only **1.17 kWh/kg** is below electron beam, forging, injection molding, and FDM .

*DOE-AMO, L. Love*

**Less Waste**

Titanium bracket for aircraft. reduced buy-to-fly ratio (ratio of material weight purchased vs. final component) from **33:1 to < 2:1**

*DOE-AMO, B. Peter*

# Big Area Additive Manufacturing (BAAM)

- **Obstacle:** Most additive processes are slow (1-4 $in^3$/hr), use higher cost feedstocks, and have small build chambers.
- **Solution:** ORNL has worked with equipment manufacturers and the supply chain to develop large scale additive processes that are bigger, faster, cheaper, and increase the materials used.

- **Large Scale Printers**
  - Cincinnati System 8'x20'x6' build volume
- **Fast Deposition Rates**
  - Up to 100 lbs/hr (or 1,000 ci/hr)
- **Cheaper Feedstocks: Pellet-to-Part**
  - Pelletized feed replaces filament with up to 50x reduction in material cost
- **Better Materials**
  - Higher temperature materials
  - Bio-derived materials
  - Composites Hybrids

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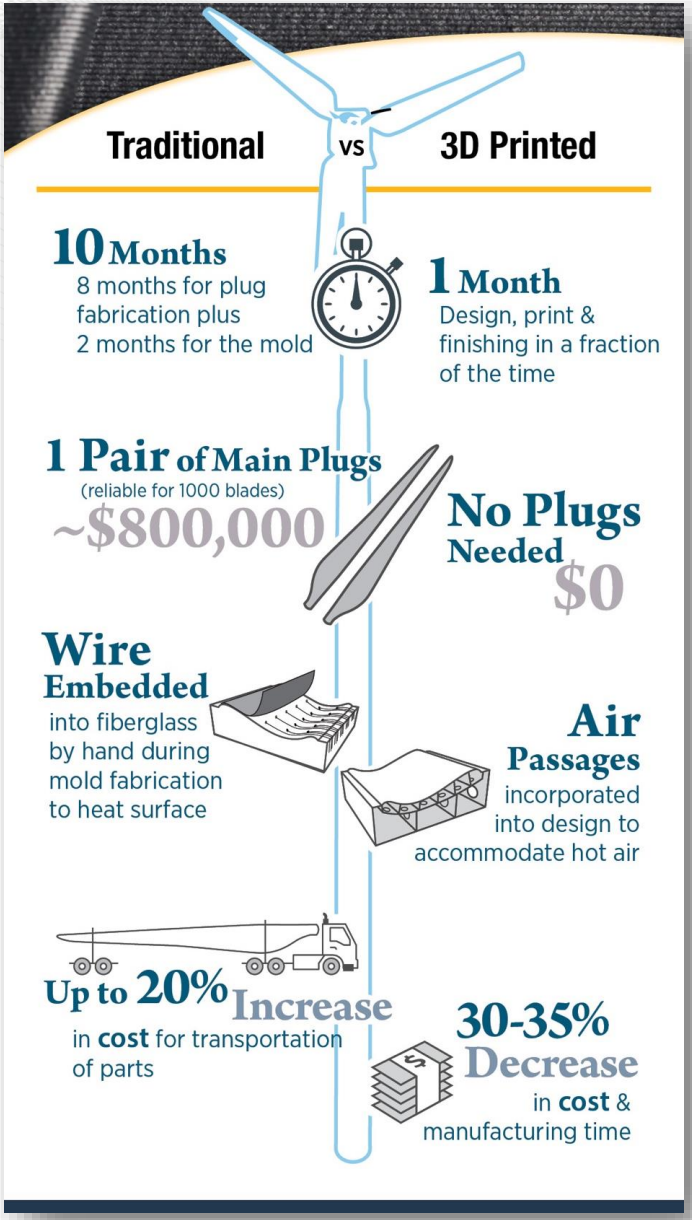
# Innovation in the Design and Manufacturing of Wind Power




- **Obstacle:** Although wind energy is among the fastest growing clean energy technologies, there are still critical challenges in achieving our national clean energy goals
- **Solution:** By utilizing large-scale additive manufacturing, ORNL researchers were able to redesign the traditional mold, eliminating unnecessary parts and procedures. Creating unique opportunities in this traditionally time consuming process.

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# Digitally Manufactured Molds Successfully Withstand Autoclave

ORNL's digitally **manufactured, high temperature thermoplastic** molds withstood industrial autoclave cycles for the first time ever!

November 2015:

Industry partners came to MDF to collaborate on tooling development effort.

**6 new materials** were successfully tested on the **BAAM-CI** during these trials

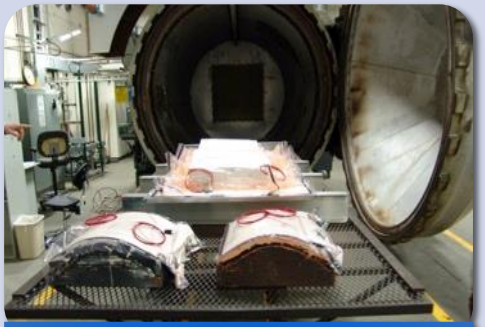
March 2016:

Over the course of three weeks, **4 tools** were fabricated using the 2 selected high temperature materials

Tools were **100% digitally manufactured**

**No touch labor** was involved

Each tool was printed in **1 hour** & machined in **4 hours as opposed to the normal 14 week lead time**



April 2016:

The 4 tools were taken to an industry partner's facility for testing.

The tools **withstood 2 autoclave cure cycles**

This was the **1st successful trial of 100% digitally manufactured tools in autoclave cure cycles**

- **Obstacle:** Die and tool companies decreased by 37% in less than a decade. Tooling is expensive and can take large lead times.
- **Solution:** ORNL is evaluating additive manufactured tools for use in autoclaves for composite fabrication.

TRUE DESIGN · TECHMER PM POLYMER MODIFIERS · Ford · BOEING · CINCINNATI CINCINNATI INCORPORATED · NAVAIR · BASF We create chemistry · OAK RIDGE National Laboratory

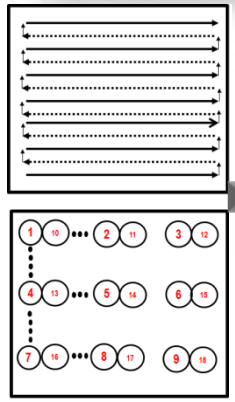
# Microstructure and Material Properties can be Controlled at a Local Level

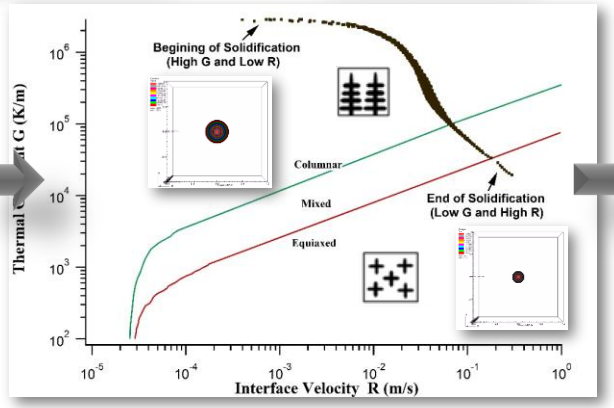
**Process Parameters Control Solidification in Electron Beam Additive Manufacturing**

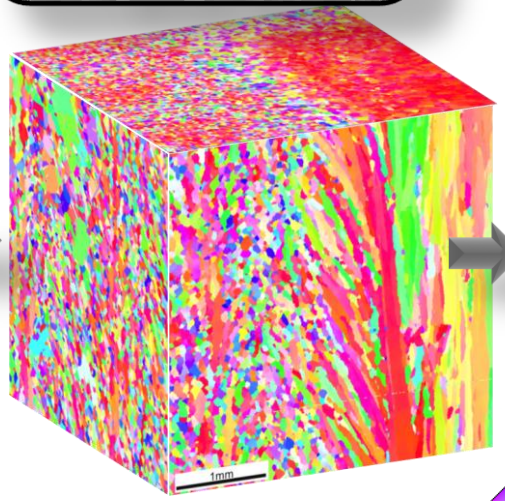
**Design Novel Melt Scan Strategy**

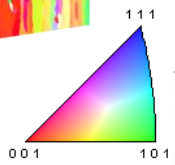
**Numerically Optimize the Process For Site Specific Crystallographic Texture Control in Actual Parts**

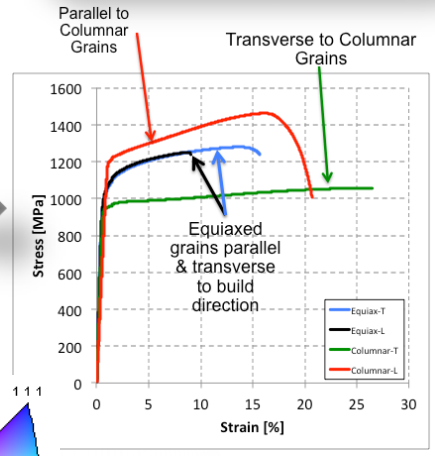
**Demonstrate Local Property Control for Improved Performance**






- **Obstacle:** We currently optimize process parameters for geometric control, not microstructure and properties.
- **Solution:** Combine HPC modeling with understanding of solidification behavior to change the microstructure and properties, with minimal trial and error optimization.

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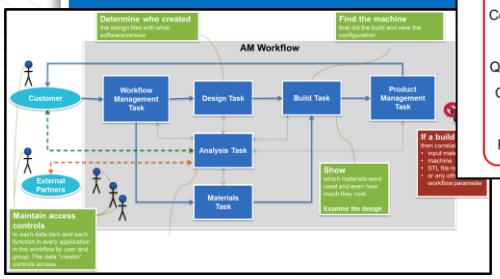
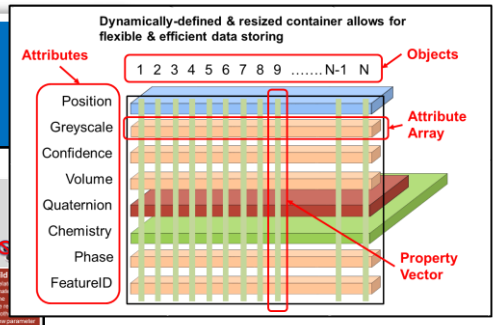
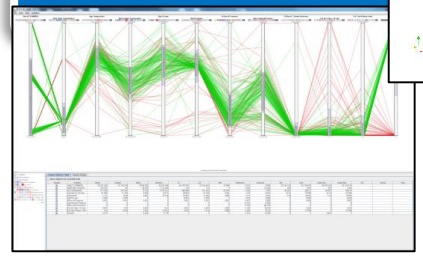
# Understanding and Utilizing of Digital Data is Imperative for AM

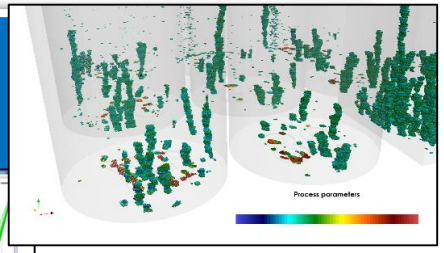
## Data Management & Tracking



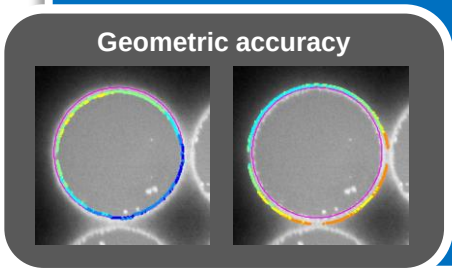



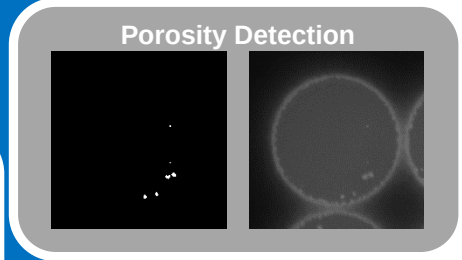

## n-D Data Visualization



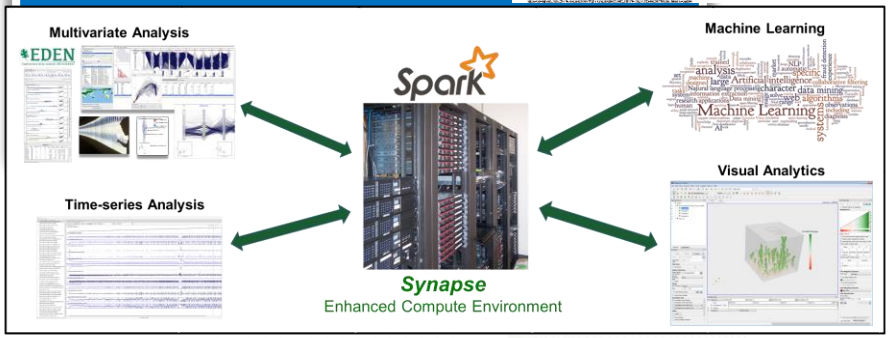



## Computer Vision / Image Processing




## Machine Learning / Statistical Analysis




- **Obstacle:** Spatial-temporal changes in process parameters and complexity in parts make qualification of additive components costly and difficult.
- **Solution:** Develop computational framework to analyze and visualize data from in-situ sensors in order to qualify and certify components.

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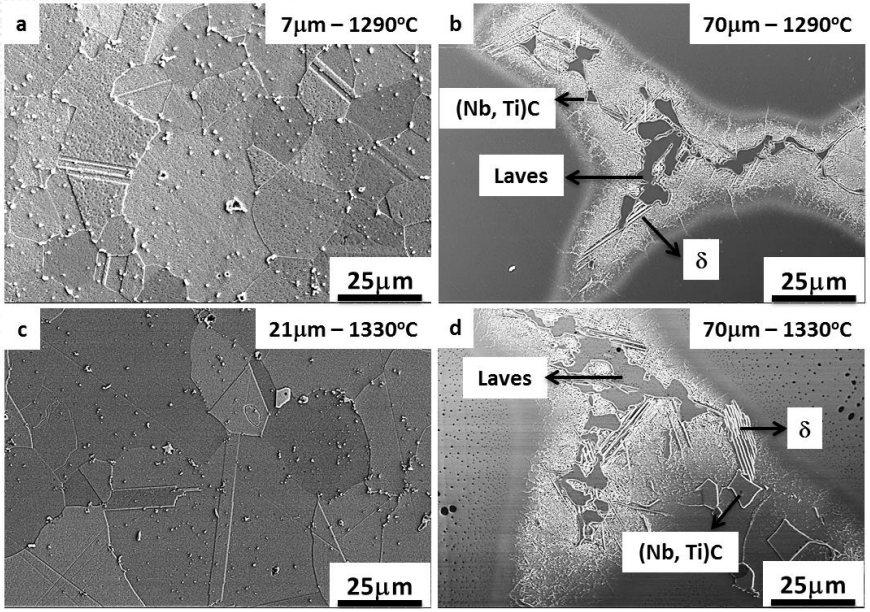
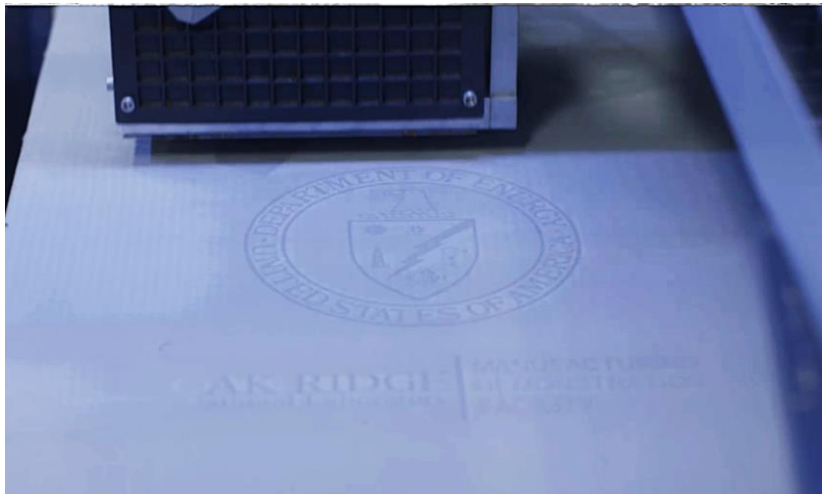
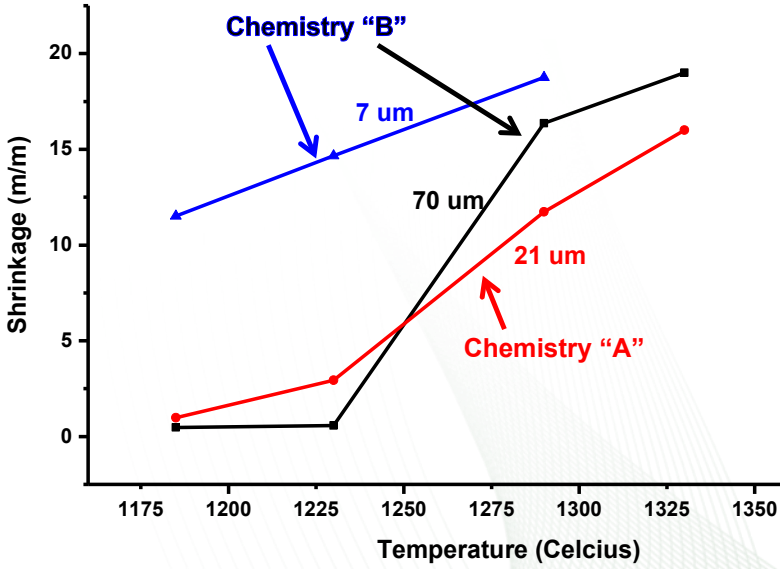
# Fully Dense Inconel 718 Binder Jet Components



- **Obstacle:** Difficult to get fully dense components with only applying temperature (no pressure) due to sluggish diffusion kinetics.
- **Solution:** Develop process methodologies based on supersolidus liquid phase sintering to control consolidation and shape.

**Change in Linear Shrinkage – Increases with the formation of liquid phase**

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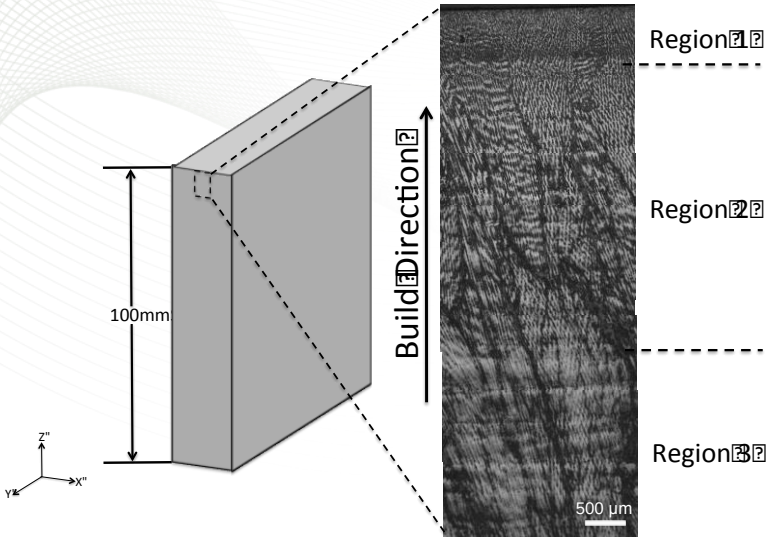
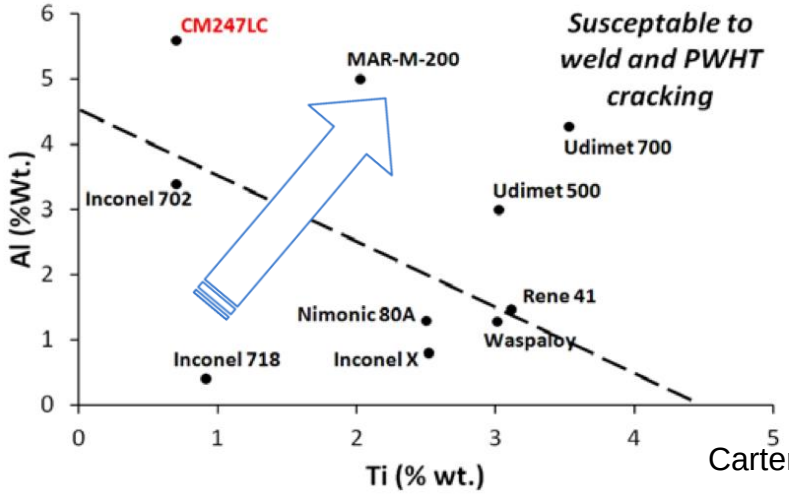
# High Temperature Metals AM

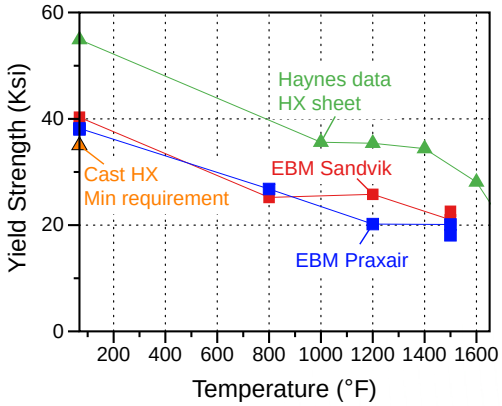
Increased Performance, Processing Challenges

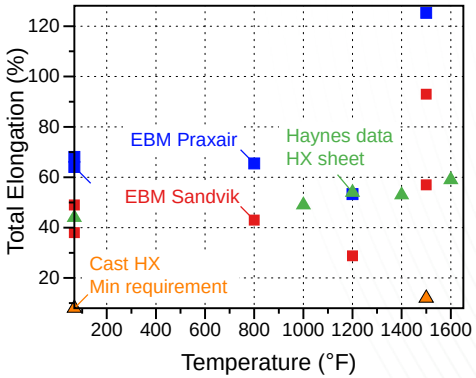


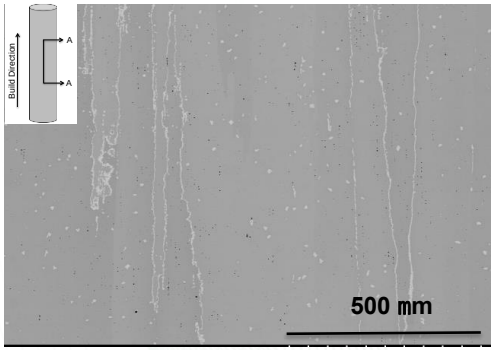

Carter (2012)

- **Obstacle:** Most high temperature alloys used today were not designed for additive manufacturing, resulting in detrimental precipitates and non-optimal properties.
- **Solution:** Selection and/or design of other alloys that could increase the operating temperatures and fully utilize complex geometries by additive processes.




**Electron Beam Powder Bed Deposited Inconel X**

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